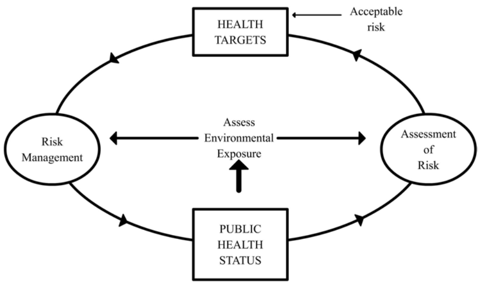

5

Excreta-related infections and the role of sanitation in the control of transmission

Richard Carr[1]

This chapter examines the role sanitation (in its widest sense) plays in preventing the transmission of excreta-related diseases. The proper management of excreta acts as the primary barrier to prevent the spread of pathogens in the environment. It, thus, directly impacts disease transmission through person-to-person contact, water and the food chain. This chapter focuses on the health dimensions and relative importance of sanitation measures, and discusses technical options for the containment and treatment of excreta. It highlights the need to consider water-related guidelines and standards in terms of the 'greater picture', utilising an integrated approach rather than proceeding on a case by case basis.

[1] With contributions from Martin Strauss

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5.1 INTRODUCTION

Human excreta and the lack of adequate personal and domestic hygiene have been implicated in the transmission of many infectious diseases including cholera, typhoid, hepatitis, polio, cryptosporidiosis, ascariasis, and schistosomiasis. The World Health Organization (WHO) estimates that 2.2 million people die annually from diarrhoeal diseases and that 10% of the population of the developing world are severely infected with intestinal worms related to improper waste and excreta management (Murray and Lopez 1996; WHO 2000a). Human excreta-transmitted diseases predominantly affect children and the poor. Most of the deaths due to diarrhoea occur in children and in developing countries (WHO 1999).

Proper excreta disposal and minimum levels of personal and domestic hygiene are essential for protecting public health. Safe excreta disposal and handling act as the primary barrier for preventing excreted pathogens from entering the environment. Once pathogens have been introduced into the environment they can be transmitted via either the mouth (e.g. through drinking contaminated water or eating contaminated vegetables/food) or the skin (as in the case of the hookworms and schistosomes), although in many cases adequate personal and domestic hygiene can reduce such transmission. Excreta and wastewater generally contain high concentrations of excreted pathogens, especially in countries where diarrhoeal diseases and intestinal parasites are particularly prevalent. Therefore for maximum health protection, it is important to treat and contain human excreta as close to the source as possible before it gets introduced into the environment.

Although the principal focus of the guideline documents examined in this book is water, in many settings other disease transmission pathways are at least as important. In microbiological terms, the traditional approach of examining each guideline area in isolation ignores the inter-related pathways and also the root of the problem, namely excreta and inadequate hygiene.

5.2 TRANSMISSION ROUTES

Human excreta may contain many types of pathogens. When these pathogens are introduced into the environment some can remain infectious for long periods of time (Table 5.1) and, under certain conditions, they may be able to replicate in the environment. The presence of pathogens presents a potential threat to human health. However, for an actual risk of disease an infectious dose of the excreted pathogen must reach a human host.

Table 5.1. Pathogen and indicator survival in different environmental media

	Pathogen survival (time in days unless otherwise indicated)			
Organism	Freshwater	Saltwater	Soil	Crops
Viruses	11–304	11–871	6–180	0.4–25
Salmonellae	<10	<10	15–100	5–50
Cholera	30	+285	<20	<5
Faecal coliforms	<10	<6	<100	<50
Protozoan cysts	176	1yr	+75	ND
Ascaris eggs	1.5yr*	2*	1–2 yr	<60
Tapeworm eggs	63*	168*	7 months	<60
Trematodes	30-180	<2	<1*	130**

ND No data; * Not considered an important transmission pathway; ** Aquatic macrophytes
Sources: Feachem *et al*. 1983; Mara and Cairncross 1989; National Research Council 1998; Robertson *et al*. 1992; Rose and Slifko 1999; Schwartzbrod 2000; Tamburrini and Pozio 1999.
Note: Differing survival times for each organism (or group of organisms) may be related to temperature.

Disease transmission is determined by several pathogen-related factors including:

- An organism's ability to survive or multiply in the environment (some pathogens require the presence of specific intermediate hosts to complete their lifecycles).
- Latent periods (many pathogens are immediately infectious, others may require a period of time before they become infective).
- An organism's ability to infect the host (some pathogens can cause infections when present in small numbers e.g. *Ascaris*, others may require a million or more organisms to cause infection; Feachem *et al*. 1983).

Disease transmission is also affected by host characteristics and behaviour, including:

- immunity (natural or as a result of prior infection or vaccination)
- nutritional status
- health status
- age
- sex
- personal hygiene
- food hygiene.

In general, pathogenic micro-organisms may be transmitted from source to new victim in a number of ways including direct person-to-person spread and indirect routes including inanimate objects (fomites), food, water or insect vectors.

Table 5.2 details a selection of faecal-oral pathogens and their transmission routes. As the table shows, multiple transmission routes are the norm, rather than the exception, for many pathogenic organisms.

Table 5.2. Selected faecal-oral pathogens and selected transmission routes (adapted from Adams and Moss 1995)

Pathogen	Important reservoir/carrier	Transmission			X in food
		water	food	p-to-p	
Campylobacter jejuni	Variety of animals	+	+	+	+
Enterotoxigenic *E. coli*	Man	+	+	+	+
Enteropathogenic *E. coli*	Man	+	+	+	+
Enteroinvasive *E. coli*	Man	+	+	Ni	+
Enterohaemorrhagic *E. coli*	Man	+	+	+	+
Salmonella typhi	Man	+	+	±	+
Salmonella (non-*typhi*)	Man and animals	±	+	±	+
Shigella	Man	+	+	+	+
Vibrio cholerae O1	Man, marine life?	+	+	±	+
Vibrio cholerae, non O1	Man and animals	+	+	±	
Hepatitis A	Man	+	+	+	–
Norwalk agents	Man	+	+	Ni	–
Rotavirus	Man	+	ni	+	–
Cryptosporidium parvum	Man, animals	+	+	+	–
Entamoeba histolytica	Man	+	+	+	–
Giardia lamblia	Man, animals	+	±	+	–
Ascaris lumbricoides	Man	–	+	–	–

X in food - multiplication in food p-to-p – person-to-person
+ yes ± rare - no ni - no information

Figure 5.1 outlines the routes of transmission, important pathogen and host-related transmission factors and also possible barriers to transmission for excreted pathogens. As Figure 5.1 illustrates, sanitation is the primary barrier for preventing faecal-oral disease transmission. If excreta disposal is ineffective or non-existent (or other animals serve as sources of excreted pathogens) other measures must be taken to avoid disease transmission. Removing or destroying infectious agents by disinfecting drinking water prior to consumption or preparation of food; cleaning hands, utensils, and surfaces before food preparation and consumption; and cooking food thoroughly are interventions that will reduce disease transmission (WHO 1993). For example, the simple act of washing one's hands with soap can reduce diarrhoea by a third (WHO 2000a).

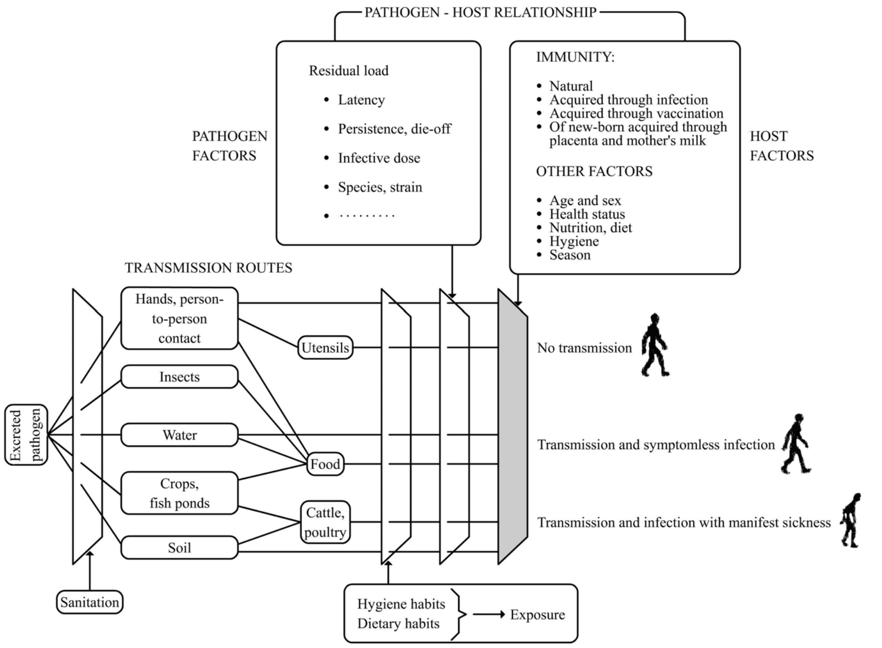

Figure 5.1. Faecal-oral pathogen transmission routes.

Faecally contaminated water, both marine and fresh, is a frequent cause of food-borne illness. For example, some shellfish (such as mussels, oysters, and clams) obtain their food by filtering large quantities of water and are therefore particularly likely to accumulate contamination. Excreta-related human pathogens, heavy metals and other chemical contaminants are taken in with the food particles and can be concentrated in the tissues. Shellfish are also frequently eaten raw or partially cooked. Fish, and non-filter feeding shellfish (crabs, lobsters, prawns, shrimps) grown in faecally contaminated water containing high levels of human pathogens can also concentrate pathogens in their intestinal tracts and on their skin surfaces. When concentrations of faecally derived bacteria exceed a certain level they can be found in muscle tissues (WHO 1989). Infection may occur when the contaminated fish is consumed raw or lightly cooked. Food handlers may also be at risk during preparation of the contaminated product.

When untreated or inadequately treated wastewater or excreta (faecal sludge) is applied to soil and crops, disease transmission can occur. The persons at risk are the farmers, farm workers and their families as well as consumers of crops produced in such a way. The use of inadequately treated wastewater in irrigation and of faecal sludges in soil amendment and fertilisation is especially associated with elevated prevalence of intestinal helminth infection. For example, in a study in Mexico, irrigation with untreated or partially treated wastewater was directly responsible for 80% of all *Ascaris* infections and 30% of diarrhoeal disease in farm workers and their families (Cifuentes *et al*. 2000). Trematode infections are caused by parasitic flatworms (also known as flukes) that infect humans and animals. Infected individuals transmit trematode larvae in their faeces. Infections with trematode parasites can cause mild symptoms such as diarrhoea and abdominal pain or, more rarely, debilitating cerebral lesions, splenomegaly and death, depending on the parasite load. In many areas of Asia where trematode infections are endemic, untreated or partially treated excreta and nightsoil are directly added to fishponds. The trematodes complete their lifecycles in intermediate hosts and subsequently infect fish, shellfish, or encyst on aquatic plants. Humans become infected when they consume the fish, shellfish, or plants raw or partially cooked. It has been estimated that more than 40 million people throughout the world are infected with trematodes and that over 10% of the global population is at risk of trematode infection (WHO 1995).

5.3 THE ROLE OF IMPROVED EXCRETA MANAGEMENT

Numerous studies have shown that the incidence of many diseases is reduced when people have access to, and make regular use of, effective basic sanitary installations. As previously illustrated in Table 5.1 and Figure 5.1, it is particularly important to keep pathogens out of the environment in the first place because many of these organisms are capable of surviving for long periods of time under different conditions. Therefore, effective excreta management at the household and community levels produces far ranging societal benefits by helping to protect water resources and the food supply from faecal contamination. The following sections describe the health benefits of improved excreta management and provide an overview of the current state of coverage worldwide.

5.3.1 The health dimension of poor sanitation

In the Global Burden of Disease (GBD) study (outlined in detail in Chapter 3) disability adjusted life years (DALYs) were ascribed to 10 selected risk factors. Water, sanitation (i.e. excreta disposal) and hygiene accounted for the second biggest percentage of DALYs behind malnutrition. Worldwide, it is estimated that there are approximately 4 billion cases of diarrhoea per year (resulting in 2.2 million deaths), 200 million people with schistosomiasis and as many as 400 million people infected with intestinal worms (Murray and Lopez 1996; UN 1998; WHO 2000a,b). All of these diseases are largely excreta-related. In less developed countries, poor nutritional status and poverty exacerbate morbidity and mortality associated with excreta-related diseases. For example, most deaths attributed to diarrhoea occur in children below the age of five (WHO 2000b). Rice *et al*. (2000) reviewed 21 studies on infant mortality associated with diarrhoea and found that children with low weight for their age had a much higher risk of mortality. Overall, malnutrition is thought to have a role in about 50% of all deaths among children worldwide.

Two literature reviews assessing the health impact of water and sanitation interventions have been published (Esrey *et al*. 1985, 1991). The first review focused on water and sanitation interventions with one of three outcomes (diarrhoea or a specific pathogen e.g. *Shigella* spp., nutritional status and mortality). The second study expanded the literature on diarrhoea or similar outcomes to include: ascariasis, dracunculiasis, hookworm, schistosomiasis and trachoma as well as diarrhoea. Median values, rather than means, were used to summarise the findings.

In general, impacts measured as reduction in morbidity ranged from low (4% for hookworm) to high (78% for guinea worm). The mean reduction from diarrhoea from the better studies was 26%, ranging from 0–68%. Different levels of impact (summarised in Table 5.3) were found according to which intervention (i.e. improved excreta disposal, water quality, water quantity or hygiene) was examined. The largest effect was seen for interventions focusing on improved excreta disposal, reflecting excreta as being the source of pathogens and the multiple routes of transmission. Moreover, it is important that all members of a community, particularly the children, make use of improved sanitation installations. Children are frequently the victims of diarrhoeal disease and other faecally/orally transmitted illnesses, and thus may act as sources of pathogens. Getting children to use sanitation facilities (or designing child-friendly toilets) and implementing school sanitation programmes are important interventions for reducing the spread of disease associated with waste and excreta (WHO 1993).

Combining the results of the many studies and reviews conducted, it becomes evident that improvements in excreta management, hygiene and water supply may reduce diarrhoeal morbidity, diarrhoea mortality and child mortality by significant amounts (WHO 1993). For example, Esrey *et al*. (1991) found reductions in diarrhoea mortality and overall child mortality of 65% and 55% respectively when improved water and sanitation were introduced. However, the size of the impact is likely to vary according to a wide range of factors, including current sanitary conditions, food supply, breast-feeding habits, education level and uptake of new facilities and behaviours. Clearly, tackling the problem at source assists in reducing transmission via all routes.

Table 5.3. Reduction in diarrhoeal morbidity from specified water and sanitation improvements based on rigorous studies (Esrey *et al*. 1991)

Water and sanitation measure	Percentage reduction in diarrhoea morbidity
Sanitation (improved excreta disposal)	36
Improved hygiene	33
Water and sanitation	30
Water quantity	20
Water quality and quantity	17
Water quality	15

5.3.2 Sanitation coverage

Despite the fact that access to an adequate water supply and sanitation is a fundamental need (and, indeed, arguably a right) for all people, a recent survey shows that almost two and a half billion people do not have access to improved sanitation (WHO 2000a).

As might be expected, sanitation coverage varies dramatically around the world, as illustrated in Figure 5.2. While Figure 5.2 shows the differences between regions, it does not show the fact that the percentage coverage is barely increasing over time. Table 5.4 shows sanitation coverage for Africa and at the global level in 1990 and 2000. It can be seen that increases on a global scale are negligible, while in Africa coverage is standing still or even decreasing. It is also likely that much of the 'improvement' seen may be due to a change in reporting methods.

It can been seen from Figure 5.2 and Table 5.4 that the situation is particularly severe in rural areas, where coverage lags behind that reported from urban areas. However, increasing urbanisation and concentrations of poor in urban slums is likely to be associated (in many cases) with higher risks of transmission, thus posing much greater sanitation challenges.

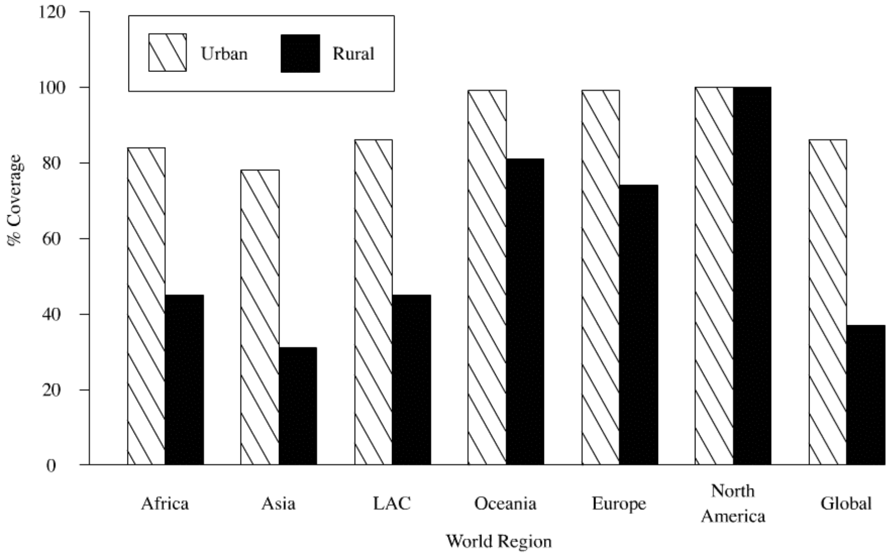

Figure 5.2. Global coverage of sanitation by world region in 2000 (WHO 2000a).

While these figures are disturbing in their own right they do not tell the whole story, as sanitation is not just the presence of available facilities (although that is a start), but for it to be effective it is also the proper use and maintenance of the facilities.

Table 5.4. Sanitation coverage in 1990 and 2000 globally and in Africa (WHO 2000a)

	1990 pop. in millions				2000 pop. in millions			
	Total Pop.	Pop. served	Pop. unserved	% served	Total pop.	Pop. served	Pop. unserved	% served
Global								
Urban	2292	1869	423	82	2844	2435	409	86
Rural	2974	1029	1945	35	3210	1201	2009	37
Total	5266	2898	2368	55	6054	3636	2418	60
Africa								
Urban	197	166	31	84	297	249	48	84
Rural	418	205	213	49	487	217	270	45
Total	615	371	244	60	784	466	318	60

From an industrialised country perspective it is often hard to visualise the sanitation conditions that may be experienced in a developing country. Box 5.1 outlines a scenario detailing some of the conditions experienced by millions of impoverished people in developing countries, and places the sanitation situation in context of other risk factors and general living conditions.

Box 5.1. Low-income peri-urban neighbourhood.

The neighbourhood is located in a city in a tropical coastal area with perennially high temperatures (between 28 and 35ºC). A typical family might consist of two adults and four children (two further children having died before the age of two after repeated and heavy attacks of diarrhoea). The family occupies one rented room in a brick-built, tin-roofed, one-storey compound house. The father finds occasional employment as a daily labourer, while the elder children sell goods and gadgets at traffic lights. The family fetches water from a neighbourhood/communal tapstand some 100 metres away from their home. The supply to the tapstand is intermittent (every second day for two hours). The nearest excreta disposal facility is a communal toilet located close to the public tapstand. The user's fees for the toilet, taken by the neighbourhood committee, are improperly used (misappropriated) and so the toilet is not maintained properly, leading to the surrounding area being used for defecation. The family also uses buckets for night-time defecation which are emptied on to an unused piece of land close by. All the children of the compound aged four or under defecate indiscriminately in the lane outside their home.

The children typically experience several episodes of diarrhoea per year. The nationwide introduction of oral rehydration therapy seems to have some effect in preventing death due to diarrhoeal attacks, but chronic malnutrition is a problem. There is a high prevalence of ascariasis and hookworm infection among children aged two or over. The four children all experienced hepatitis A infection in their early childhood and developed immunity. The parents are struck by typhoid fever, amoebic or bacillary dysentery on average about once a year.

5.4 EXCRETA DISPOSAL

The problem of excreta disposal is clearly as old as mankind itself and the need for careful disposal is highlighted in a number of religious books including Hindu, Islamic and Christian texts. The following sub-sections outline a number of excreta management options. Although these are essentially 'technological' answers, albeit of varying complexity, it is important to remember that experience indicates that technology alone is inadequate to secure health gains. Without local interest, involvement and commitment facilities may remain unused or fall out of use. As Samanta and van Wijk (1998) point out 'access to a latrine is not the same as adoption of sanitary practices in dealing with human waste'. Moreover, technical measures for improved sanitary installations, excreta treatment and use or disposal must be complemented by personal and domestic hygiene measures. This section focuses on technical measures for excreta disposal and treatment.

There are numerous technical options for excreta management, many of which, if properly designed, constructed, operated and maintained will provide adequate and safe service as well as health benefits. It is necessary to choose technically, economically and financially feasible options for sustainable excreta management. Equally important is the involvement of all stakeholders playing a role in sanitation development, including users (or customers), community organisations, authorities and entrepreneurs. In particular, it is essential to involve women in the design and selection of domestic sanitation facilities. Research conducted in South Asia demonstrates that involving women in sanitation programmes has resulted in higher coverage, better maintenance of the facilities, increased hygiene awareness, and lower incidence of faecal-oral disease in the community (Neto and Tropp 2000). In addition, for sanitation programmes to be sustainable there must be the political will and institutional capacity to ensure adequate public services and the proper maintenance of sanitation systems (Simpson-Hébert and Wood 1998). Indeed, there are numerous instances where public toilets, in particular, are poorly maintained and the latrine contents inappropriately disposed. Although, happily, this is not always the case and successful schemes (often run on a franchise basis by profit-making organisations or by social organisations) exist in a number of places including Ghana and India (Gear *et al*. 1996; National Institute of Urban Affairs 1990).

It is important to note that there is no single appropriate technology for all circumstances and all socio-economic segments of a community, town or city. The more costly or, apparently, convenient technologies may not provide the greatest health benefit or may be unsustainable from an economic or technological viewpoint.

For practical purposes sanitation can be divided into on-site and off-site technologies. On-site systems (e.g. latrines) store and/or treat excreta at the point of generation. In off-site systems (e.g. sewerage), excreta is transported to another location for treatment, disposal or use. Some on-site systems, particularly in densely populated regions, require off-site treatment components as well. For example, the faecal sludges accumulating in single pit or vault latrines in urban areas and in septic tanks periodically need to be removed and treated off-site for use or disposal.

For sanitary installations to deliver health benefits they need to be able to:

- isolate the user from their own excreta
- prevent nuisance animals (e.g. flies) from contacting the excreta and subsequently transmitting disease to humans
- contain the excreta and/or inactivate the pathogens.

It must be noted that not all excreted components contain pathogens. Urine in most circumstances is sterile (unless it is cross-contaminated by faecal matter caused by the inappropriate design, or use, of the urine-diverting toilet) and contains most of the agriculturally useful nutrients. To reduce required excreta storage volumes, some sanitation facilities promote the separation of urine and faeces. Once it is separated, and diluted, urine can be used immediately as a crop fertiliser with minimal risk to public health (Esrey 2000; SEPA 1995; Wolgast 1993).

5.4.1 Technical sanitation options

This sub-section examines a number of selected technical sanitation options (Franceys *et al*. 1992; Mara 1996b; WHO 1996; WELL/DfID 1998), including both on- and off-site alternatives.

5.4.1.1 On-site installations

On-site installations comprise so-called ‘dry’ and ‘wet’ systems. Pit, ventilated improved pit (VIP) and urine-separating latrines are operated without flush water and are designated ‘dry’. Pour-flush latrines and septic tanks are ‘wet’ systems in that they require water, albeit only two or three litres in the case of pour-flush latrines.

Latrine systems may be built with either one or two pits or vaults, depending on affordability, housing density and socio-cultural habits. In the case of two pit/vault systems, only one is in active use at any one time with the other being used to allow pathogen inactivation and decomposition of the excreted material. A storage period of 6–12 months is required in a tropical, year-round warm climate to render the faecal sludges of dry or pour-flush latrines safe for handling and agricultural use (Feachem *et al*. 1983; Peasey 2000; Strauss 1985; WHO 1996). Such pit contents will satisfy the WHO guideline equivalent of 3–8 nematode eggs/g of dry matter.

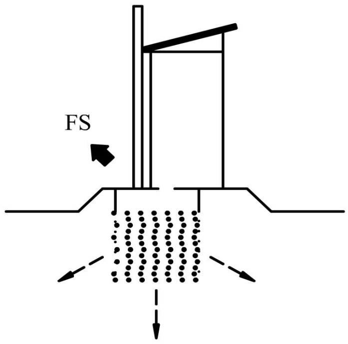

Figure 5.3. VIP latrine (FS = faecal solids).

The VIP latrine (Figure 5.3) is an improvement over a simple pit as the screened vent pipe removes odours from the interior of the toilet superstructure and helps to prevent problems with flies and mosquitoes. Reducing the ability of flies (and other insects) to transmit pathogenic organisms from faeces to food or drink is important in public health terms.

In the no-mix latrine (Figure 5.4), urine and faecal material are collected separately. The diluted urine can be used immediately as a fertiliser. Deposited faeces must be covered with lime, ash, or earth to lower the moisture content, reduce the smell and make the faecal material less attractive to flies.

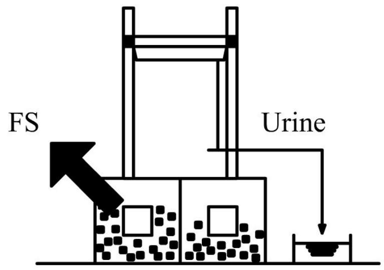

Figure 5.4. Double vault no-mix latrine (FS = faecal solids)

Like ‘dry’ latrines, pour-flush toilets can be built with one or two pits for excreta disposal. They have a special pan, which is cast into the cover slab and is preferably equipped with a water seal for odour and fly control. Pour-flush latrines require between two and three litres of water per flush and are not suitable for areas with cold climates, impermeable soils or high water tables where the groundwater is a source of drinking water (WHO 1996). They are also inappropriate where the use of solid objects for anal cleansing is the custom, as these may cause siphon blockage.

Septic tanks (Figure 5.5) are watertight chambers sited below ground level that receive excreta and flush water ('blackwater') from flush toilets and also household sullage or 'greywater'. The solids settle out and undergo partial anaerobic degradation in the tank, while the effluent stays in the tank for a short period before, according to conventional design, overflowing into a soakpit or drainfield. Septic tanks should not be used where the soil is impermeable or where the water table is high and the groundwater is a source of drinking water (WHO 1996). Septic tanks may be used in sanitation upgrading, by making them an integral part of low-cost sewerage and enabling a solids-free transportation of wastewater (Mara 1996a).

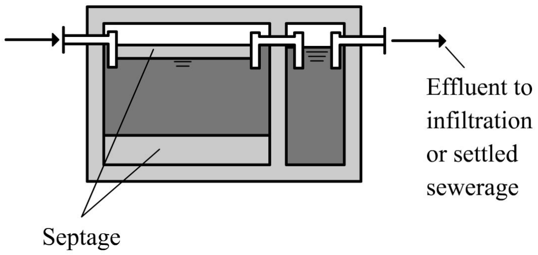

Figure 5.5. A septic tank.

The faecal material or sludges accumulating in septic tanks, single-pit or vault latrines and unsewered public toilets in urban areas must periodically be removed and hauled away. In many developing countries, however, reasonable emptying intervals are rarely observed due either to cost, inefficient emptying services or access difficulties. As a result, in many cities that rely on on-site sanitation systems only a fraction of the faecal sludge generated is collected and accounted for.

5.4.1.2 Groundwater pollution risks from on-site sanitation

Where on-site sanitation systems with unsealed pits for excreta storage or with liquid soakage pits and drainfields are used, there exists a potential risk of microbiological and chemical groundwater pollution. The risk is particularly high for shallow groundwater covered by only a few metres of permeable strata. It is virtually zero for groundwater flowing in deeper aquifers, which are usually protected by impermeable strata. This section focuses on the risk from pathogens.

As early as the 1950s a safety distance of 15–30 metres between latrines and wells was stipulated (California State Water Pollution Control Board 1954;

Wagner and Lanoix 1958). This rule of thumb has persisted and been repeatedly cited since then. It does not, however, take into account the fact that actual groundwater pollution and the concurrent public health implications are dependent on many factors and conditions. It may be overly strict in some and too lenient in other cases. In many cases, such as in densely populated low-income housing areas of cities in developing countries, demanding a distance of even 15 m is impractical. Several factors play a role and must interact for a potential risk of groundwater pollution to turn into actual pollution. The important factors are:

- Characteristics of the strata (soils, rocks) between an infiltration pit or field and the groundwater table.
- Distance between the bottom of a latrine pit and the groundwater table, i.e. the depth of the so-called unsaturated zone.
- Whether the latrine pit leaches into the groundwater (seasonally or permanently).
- The hydraulic gradient and the rate of groundwater flow.
- Hydraulic loading from the sanitary installation; this is related to the type of on-site installation (i.e. ‘dry’ latrines with minimal water use versus ‘wet’ installations such as pour-flush latrines or septic tank soak pits receiving both black and greywater).
- Depth of the filter screen below the groundwater surface in a tube or bored well (vertical permeability in unconsolidated soils is much lower than horizontal permeability).
- The temperature in the soil strata and in the aquifer (this is the major factor determining pathogen die-off).

Unsaturated, well-graded and finely divided, so-called unconsolidated soils constitute a very effective defence against the penetration of micro-organisms, helminth eggs and protozoal cysts and their reaching the groundwater table (Lewis *et al*. 1982; Schertenleib 1988). Therefore, the ideal situation is where the groundwater level does not reach latrine pits year-round and an unsaturated soil layer can act as a permanent barrier.

5.4.1.3 Faecal sludge treatment

Few developing countries, to date, have seen investment in faecal sludge treatment as a priority, due to the paucity of treatment options suited to the economic and institutional conditions prevailing in many developing countries. However, several basic options depending on the goal of treatment, the type of faecal sludge collected, and economic and climatic conditions may prove suitable (Heinss *et al*. 1998; Montangero and Strauss 2000; Strauss *et al*. 2000). The sludges may be treated separately, e.g. in pond systems (with or without prior solids separation in settling tanks), unplanted or planted sludge drying beds or drying lagoons. Alternatively, options exist which treat the sludges in combination with wastewater (e.g. in pond systems comprising separate pre-treatment of faecal sludges and combined treatment of faecal sludge liquids with municipal waste), solid organic waste (so-called co-composting) or with sewage treatment plant sludge. The treatment of faecal sludges, whether singly or in combination with other wastes, calls for criteria and procedures that differ from those used for wastewater. Faecal sludges are usually low in chemical contaminants and thus lend themselves well to agricultural use; if they are used in this way nematode egg counts would be the most appropriate criterion to assess suitability.

Faecal sludge collection, haulage and treatment strategies should, ideally, focus on decentralised solutions in order to minimise haulage distances, prevent the uncontrolled dumping of sludges, keep land requirements for individual treatment schemes modest and keep the distance to suitable agricultural areas short.

5.4.1.4 Off-site (sewered) sanitation

Sewerage is the removal of excreta, flushing water and household greywater through a pipe network to a treatment works or a point of disposal or use. In order to minimise environmental pollution and disease transmission it is important that the sewage is properly treated and not allowed to flow untreated into rivers or other water bodies. Estimates suggest that less than 5% of all sewage in developing countries receives any treatment before it is discharged into the environment (World Resources Institute 1998). Industrialised countries also need to improve their sewage, excreta and sludge management practices. In the US, for example, the number of waterborne disease outbreaks and the number of affected individuals per outbreak has increased since 1940 (Hunter 1997). Similarly, water quality monitoring of major European rivers indicates that average coliform levels have been steadily increasing for decades (Meybeck *et al*. 1990).

The cost of a conventional sewerage system (which is in the order of 20–70 times that of dry on-site alternatives; see Table 5.7) and its requirement for a piped water supply preclude its adoption in many communities in developing countries (Franceys *et al*. 1992). Low-cost sewerage (a sewerage alternative whereby the design and construction standards associated with conventional sewerage are greatly relaxed) is increasingly being adopted. Although the costs still exceed those of on-site systems (except septic tanks) by a factor of 5–40 (see Table 5.7) low-cost sewerage might be the option of choice in very densely inhabited areas where a regular and adequate water supply is affordable and available.

Conventional sewerage combined with sewage treatment, which is the predominant mode of excreta management in many industrialised countries, is often considered to be the ‘gold standard’ in terms of excreta disposal and achieving health benefits. For this reason it has often been uncritically transferred to developing countries. However, in many instances it has proved to be far from ideal, not least because of its high cost and need for in-house water supply. The myth that health benefits accrue only from a ‘conventional’ sewerage system is gradually fading away as suitable alternative sanitation options have been revitalised, developed and promoted during recent decades. There has also been recognition of the need to reduce serious downstream health impacts associated with waterborne sewage including contamination of recreational waters and shellfish beds. As Cairncross (1989) writes:

> No one can plead ignorance of its [waterborne sewage] disadvantages as a sanitation system for low-income communities. Its excessive cost, its wasteful water consumption, its unreliability in conditions of intermittent water supply and its technical impossibility in the narrow, winding alleys of the slums and shanty towns of the Third World are only the better known arguments against it. (p. 304)

While progress in the implementation of appropriate versus industrialised country options has been made, setbacks are constantly occurring. Recently, following a cholera outbreak, the Deputy Minister of Health in Ghana declared that latrines will be phased out and homeowners will be required to install flush toilets.

5.4.1.5 Wastewater treatment

So-called ‘conventional’ wastewater treatment options (primary and secondary treatment), as are widely applied in industrialised countries, have traditionally focused on the removal of suspended solids and pollutants that require oxygen in the receiving waters to decompose (biochemical oxygen demanding substances (BOD)) and not on the reduction of pathogens and nutrients. These processes are usually difficult, and costly, to operate due to their high energy, skilled labour, infrastructure, and maintenance requirements. Tertiary treatments must be added to the process to effectively reduce pathogen and nutrient levels. A combination of different tertiary treatments such as filtration and chlorination must be used to reduce pathogen levels to very low or undetectable levels. Addition of such treatment steps, however, significantly increases the cost and complexity of the process. The cited options are, therefore, inappropriate in less industrialised or less economically advanced countries.

Waste stabilisation ponds (WSP) are receiving increasingly wide acceptance in developing countries. They can be designed to provide partial treatment (i.e. the removal of helminth eggs to protect farmers and their families who use the effluent for irrigation) or full treatment, which is equivalent to conventional tertiary treatment and achieves inactivation of viruses and pathogenic bacteria (Mara and Pearson 1998). Such effluents, according to WHO (1989), may safely be used for unrestricted vegetable irrigation (i.e. irrigation of vegetables that may be consumed uncooked). In warm climates, where land is available at low cost, WSP have, thus, become a proven method for treating wastewater. When designed properly, WSP are more effective, reliable and robust at removing pathogens than most 'conventional' treatment options. Moreover, WSP remove pathogens without the addition of costly chemicals such as chlorine, are simple to operate and maintain, and promote the use of the water and nutrient resources in the wastewater (Mara and Cairncross 1989). They do, however, have relatively large land requirements.

In order for any sanitation option to be effective it needs to either contain the pathogens or destroy them. The effectiveness of some of the options has been alluded to above. The following two sections, however, explicitly examine pathogen inactivation in general and also look at the containment and inactivation for a range of sanitation options.

5.4.2 Pathogen inactivation

Survival of pathogens derived from faeces is an important factor in disease transmission. Table 5.5 indicates survival times for different pathogens in faecal sludge under both temperate and tropical conditions.

Table 5.5. Organism survival periods in faecal sludge (Feachem *et al.* 1983; Strauss 1985) * survival periods are much shorter if faecal sludge is exposed to the sun

Organism	Av. survival time (days) in wet faecal sludge at ambient temp*	
	Temperate climate (10–15°C)	Tropical climate (20–30°C)
Viruses	<100	<20
Salmonellae	<100	<30
Cholera	<30	<5
Faecal coliforms	<150	<50
Amoebic cysts	<30	<15
Ascaris eggs	2–3 years	10–12 months
Tapeworm eggs	12 months	6 months
Trematodes	<30	<30

5.4.3 Containment

A number of sanitation options are rated on their containment ability in Table 5.6. It is important to bear in mind that containment can act at different levels, protecting the household, the community and 'society'. In the case of the VIP latrine it is easy to see that the containment acts at a household level. However, poor design or inappropriate location may lead to migration of waste matter and contamination of local water supplies putting the community at risk. In terms of waterborne sewage, the containment may be effective for the individual and possibly also the community, but effects may be seen far downstream of the original source, hence affecting 'society'.

Table 5.6. Sanitation options and their containment efficiency

Sanitation option	Containment		
	Household	Community	'Society'
Pit latrine	±	–	+
VIP latrine	+	±	+
No-mix double vault	±	+	+
Pour-flush latrine	+	±	+
Septic tanks	+	±	±
Sewerage/sewage treatment	+	±	–

+ good protection ± some protection – poor protection

Table 5.7 expands upon some of the points within Table 5.6 in terms of potential risk and effectiveness of the barrier to transmission of illness, and also examines the relative construction costs, affordability and institutional implications of selected sanitation options.

Table 5.7. Characterisation of selected excreta management and treatment options

Man/treat option†	Water*	Disease barrier/potential risks	Relative construct. cost	Affordability[a]
VIP latrines	0	Single pit installations also contain fresh excreta; pit contents thus need to be treated and precautionary measures observed during emptying, collection and transport. Groundwater pollution risk where soils are fissured or groundwater levels rise to the pit during wet seasons. Reduces potential disease transmission from flies. Pit contents of double-pit latrines are hygienically safe after storage periods of 6–12 months (tropical climate) or 18–24 months (sub-tropical climate). Such stored contents may be safely used in agriculture	1–2[b] For single pit latrine in urban or peri-urban areas; mechanically emptied every three years; including off-site treatment of faecal sludge.	6[b]
No-mix double-vault latrines	0	Handling and use of urine does not pose health risks in most situations. Hygienic safety of vault contents (as above). Potential disease transmission from flies can be reduced by covering fresh faecal matter with lime, ashes, or soil.	1[b] Manual emptying; no treatment required for pit contents.	3[b]
Pour-flush double-pit latrines	10–15	Handling and use of pit contents: as for no-mix double-vault latrines. Groundwater contamination possible where water levels are (periodically) high. Water seal must be maintained to prevent flies from contacting faeces.	1[b] Manual emptying; no treatment required for pit contents.	3[b]
Septic tanks	20–30	Septage (the settled and floating solids mixed with interstitial wastewater) require treatment as they contain the bulk of excreted pathogens carried in wastewater; high level of pathogen viability in recently deposited solids. Effluent liquids, unless allowed to infiltrate, require treatment, to minimise the pollution load on receiving waters, as they also contain pathogens. Potential pollution of groundwater if water levels are high and soils not consolidated. Fly problem minimised by water barrier.	15–25 Including infiltration system, emptying and off-site treatment of septage.	30–50

Man/treat option†	Water*	Disease barrier/potential risks	Relative construct. cost	Affordability[a]
Waste stabilisation ponds	20–100	A well designed series of ponds is capable of high pathogen removal rates, particularly in warm climates. Ponds must be designed to increase retention times and prevent short-circuiting. Some precautions may be needed to prevent disease vectors from breeding (e.g. mosquitoes or snails).	5–40 Requires large amounts of land and thus depends on the price and availability of land.	5–15
Simplified sewerage	60–100	Solids retention chambers in settled sewerage schemes contain fresh, highly pathogenic contents that require treatment and hygiene precautions in emptying and haulage. Wastewater collected through low-cost sewerage requires treatment for pathogen removal prior to use and discharge and for organics removal prior to discharge.	5–40 Decreasing with increasing housing density and number of houses connected.	12–15
Conventional sewerage	>100	Primary and secondary sewage treatments are not highly effective at reducing pathogen levels. Disinfection and/or additional tertiary treatments are required to reduce pathogen concentrations to acceptable levels.	20–70 Decreasing with increasing housing density and number of houses connected.	30–50

† Management/treatment options

* Water required for operation (litres/capita/day)

[a] Approximate total annual investment and current cost as a percentage of yearly income (assumed to amount to $180/capita and $900/household) of an average low-income household in 1990.

[b] In urban areas, latrine installations might be shared by several families; investment and annual economic cost would accordingly be lower relative to the other sanitation options (the investment cost of a VIP latrine for example, might be lower by a factor of 3–4 if used by 5–8 families instead of 1).

Sources: Cotton *et al*. 1995; Kalbermatten *et al*. 1980; Mara 1996a,b; WELL/DfID 1998; Whittington *et al*. 1992.

5.5 IMPLICATIONS FOR INTERNATIONAL GUIDELINES AND NATIONAL REGULATIONS

Poor sanitation practices lead to disease transmission through numerous pathways. To manage the risks of excreta-related disease transmission, it is important to apply a multiple barrier approach (similar to the hazard assessment and critical control point (HACCP) type programs discussed in Chapters 1 and 12) to sanitation. The use of safe sanitary installations and the appropriate handling, treatment and use of excreta are important barriers or critical control points in the transmission of faecal-oral disease. Effective excreta management programmes will reduce disease transmission via drinking water, contact with recreational water and via the food chain. As discussed earlier, when such management fails, other interventions are necessary to prevent the spread of disease. Numerous studies have helped to identify additional barriers to the spread of faecal-oral disease. Many of these barriers are related to behaviours such as good personal and domestic hygiene practices, water storage and food preparation. Therefore, behaviour modifications as well as technical sanitation solutions are necessary to reduce the transmission of excreta-related disease.

Although the guidelines under consideration in this book focus on water-related areas, it is clear from a public health perspective that consideration of sanitation provision, under the auspices of the harmonised framework, is vital in terms of both international guidelines and national standards.

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